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# A Test of Cultural Treatments Selected to Improve the Chemical and Physical Characteristics of Reclaimed Surface Mine Spoil for the Growth of Loblolly Pine in East Tennessee

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To the Graduate Council:

I am submitting herewith a thesis written by Thomas L. Simpson entitled "A Test of Cultural Treatments Selected to Improve the Chemical and Physical Characteristics of Reclaimed Surface Mine Spoil for the Growth of Loblolly Pine in East Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Forestry.

Edward R. Buckner, Major Professor

We have read this thesis and recommend its acceptance:

Ronald L. Hay, Maxwell E. Springer

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

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Accepted for the Council:

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# A TEST OF CULTURAL TREATMENTS SELECTED TO IMPROVE THE CHEMICAL AND PHYSICAL CHARACTERISTICS OF RECLAIMED SURFACE MINE SPOIL FOR THE GROWTH OF LOBLOLLY PINE IN EAST TENNESSEE

A Thesis

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Master of Science

Degree

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Thomas L. Simpson

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## ABSTRACT

Three surface mine spoil areas in East Tennessee were selected for testing the influence of the State reclamation requirements and selected supplementary treatments on the survival and growth of pines recommended for planting on various sites. A high elevation (2,800 feet) test near Caryville, Tennessee, was discarded because of poor survival of white pine and site modification by contractors working in the area.

Fertilizer tests on two established loblolly pine plantations, one on new and the other on old spoil from mining the Sewanee coal seam near Cagle, Tennessee (1,850 feet), indicated that N additions of both 50 and 100 pounds per acre increased growth; response duration appeared to increase when P was added. On the older spoil liming appeared to decrease response to N, especially at 4 tons per acre (State requirement). On new spoil the greatest growth was in plots receiving N with 2 tons of lime per acre; growth was less when lime was added at 4 tons per acre.

Trees on the older spoil were heavily mycorrhizal with <u>Pisolithus tinctorius</u> while trees on the younger spoil were essentially non-mycorrhizal, possibly accounting for greater vigor and growth on the older spoil and the absence of a response to liming. Winter injury (1976-1977) was greater in those trees that grew most rapidly during the previous growing season, especially in the older planting.

On a surface mine near Oliver Springs, Tennessee (2,250 feet elevation), application of a wetting agent and/or a NP fertilizer to the soil appeared to increase growth of trees but survival decreased when either were applied to loblolly pine at planting time. Seedlings inoculated with mycorrhizal fungi survived better and grew more than those not inoculated. Grass density appeared to be the primary factor influencing seedling survival, with high mortality in dense lovegrass.

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# CHAPTER I

## INTRODUCTION

The revegetation of surface mines is a problem closely related to the current energy crisis. Coal is the single energy source for which there is both a known supply sufficient to meet our energy needs for several decades and for which the technology of acquisition and utilization have been developed. This, coupled with the lag in development of other energy sources, has stimulated renewed efforts to exploit the readily available coal reserves. The fastest, cheapest, and safest method for obtaining coal is through surface mining; a process that is highly destructive of environmental quality. The critical nature of our energy problems will probably result in a marked increase in the amount of surface mining throughout North America, especially as research develops new and cleaner methods for obtaining energy from coal.

The largest single problem associated with this expanding industry will be the reclamation of surface mined areas to meet the demands for improved environmental quality. All states in which surface mining is widely practiced now require some form of reclamation. There is, however, considerable disagreement over the ecological desirability and economic feasibility of many of the requirements now enforced. Implementation is further handicapped by the frequent changes in reclamation requirements. Frequent updating of regulations to reflect improved technology and greater knowledge gained from experience are, however, essential to a viable reclamation program.

A major problem in minimizing the environmental impact of surface mining is the rapid erosion that occurs immediately following grading of the steep slopes that characterize most of the contour mines of East Tennessee. High fertility levels and pH above 6.0 are needed for the rapid establishment of grass species that provide the initial cover on reclaimed surface mines. Dense sod may, however, be detrimental to the establishment and early growth of the trees that are needed for long term stability. Since most laws do not require maintenance of the grass cover established in the initial reclamation, the establishment of a vigorous forest cover is essential to long term stabilization.

A high priority need in surface mine technology for East Tennessee is the development of guidelines for applying fertilizers and lime based on the physical and chemical properties of a particular mine spoil such that adequate grass cover can be rapidly established but not to the detriment of planted trees that will eventually replace the grasses in stabilizing the site.

## CHAPTER II

## LITERATURE REVIEW

The factors affecting the establishment and growth of forest tree species on surface mine spoil are highly variable and often difficult to analyze. Tree growth on mine spoil is influenced by such variables as low concentrations of soil nutrients, toxic quantities of some metallic elements, soil temperature and pH extremes, low organic matter, low soil moisture, and poor texture (Marx, 1975; Medve, 1976). Other conditions that characterize these sites are: no shade, no soil life, lack of competition with other plants during early development, and a loose soil structure that allows rapid and deep root growth (Knabe, 1964). Limstrom (1964) divided the problems encountered in revegetating surface mine spoil into two areas: site problems such as texture, aggregation, acidity, topography, grading, and vegetation, and planting problems such as species selection, methods of planting, planting stock quality, and erosion control.

Nutrient deficiencies are often a serious problem in surface mine spoils. An estimate of the annual nutrient requirements of forest trees was provided by Gessell et al. (1960):

| | |
|---|---|
| Nitrogen: | 15-60 pounds per acre |
| Phosphorus: | 2-20 pounds per acre |
| Potassium: | 5-50 pounds per acre |
| Calcium: | 20-100 pounds per acre |

Nitrogen is most commonly limiting to tree growth on spoil banks (Schramm, 1966; Duffy, 1967; Fowells and Krauss, 1959; Cornwell and Stone, 1968). Low phosphorus levels also limit tree growth on surface mine spoil in East Tennessee (Zarger, 1977). Most researchers have found that the best tree growth on mine spoil is obtained by applying both nitrogen and phosphorus (Bengtson et al., 1973; Farmer et al., 1970; Plass and Vogel, 1973; May et al., 1973). However, many times the problem lies not with the limiting elements, but with large quantities of metallic ions at toxic levels.

The elements most often present in toxic quantities are aluminum, manganese, iron, copper, and zinc (Plass, 1969; Barnhisel and Massey, 1969; Berg and Vogel, 1965). Barnhisel and Armine (1974) subjected kaolinite and mica clay minerals to coal mine solutions of sulfuric acid and reported that aluminum, iron, potassium, and silicon were released. They explained toxic levels of aluminum ions in surface mine spoils as the dissolution product of clay minerals in acid solutions. Aluminum was at toxic levels in plants where soil pH was 5.5 and below (Berg and Vogel, 1973).

Harabin and Greszta (1973) found that tree roots growing in toxic material had shortened lateral roots. They concluded that trees were unable to replace the rootlets and root hairs with sufficient speed for normal growth in toxic spoils.

Acidity and phytotoxicity are the major causes of poor survival and growth on surface mines (Wheeler, 1965; Horn, 1968; Berg, 1965). The establishment of vegetation is extremely difficult with pH below 4.0. Lowry (1960) studied the survival and growth of several conifer species on surface mine spoil in Ohio and derived the following equation for survival based on soil moisture, sand content, and soil acidity:

$$\hat{Y} = -356.28 + 14.22\,X_1 + 2.40\,X_2 + 18.71\,X_3$$

Where:

$\hat{Y}$ = Predicted survival (%)

$X_1$ = Moisture equivalent (%)

$X_2$ = Sand content (%)

$X_3$ = Soil acidity (coded)

| | |
|---|---|
| pH 2.0-3.0 | 2 |
| 3.0-4.0 | 3 |
| 4.0-5.0 | 4 |
| 5.0-6.0 | 5 |
| 6.0-7.0 | 4 |

This formula indicates that pH above 6.0 results in decreased survival of coniferous trees.

Surface mine spoil in the Central States was classified by Limstrom (1960) as follows:

| | |
|---|---|
| Toxic: | spoils having greater than 75 percent of area with pH less than 4.0 |
| Marginal: | spoils having 50-75 percent of area with pH less than 4.0 |
| Acid: | spoils having greater than 50 percent of area with pH 4.0-6.9 |
| Calcareous: | spoils having greater than 50 percent of area with pH 7.0 or above |
| Mixed: | acidity values so variable that classification is not possible. |

Another soil classification of spoil material was made by Ruffiner (1965):

| | |
|---|---|
| Slightly acid: | pH is dominantly 5.5 or better and plant performance is generally good |
| Moderately acid: | pH is between 4.0 and 5.5 and spoil may have a few extremely acid "slick spots" from pyrites |

Extremely acid: (toxic) pH is dominantly below 4.0 and may have numerous "slick spots."

Soil temperature extremes also pose serious problems in establishing trees on surface mine spoil. Schramm (1966) found that soil temperature was the limiting factor controlling tree growth in the black wastes of anthracite coal mines. He reported surface temperatures of 67 C while air temperatures were 31 C. He concluded:

> The temperature hazard to plants attempting to gain a foothold on black wastes thus is intimately connected with the presence and depth of dry surface layers. In any given waste area these in turn are dependent on amount, frequency, and spacing of precipitation, insolation between rains, air temperature, wind velocity, absolute humidity, etc.

Deely and Borden (1973) found that three to seven days without rain was sufficient for surface temperatures of mine spoil to reach 50-55 C while the air temperature ranged from 30-33 C. Darker soil exhibited maximum surface temperatures of 70 C; the average temperature difference between light and dark spoils was about 15 C. These authors also found that the maximum surface temperatures increased at an average rate of 2-4 degrees C per day for the first six to ten days after a rain.

Maguire (1955) reported that maximum surface temperatures occurred approximately eight days after an inch of moisture during the summer months and after a slightly longer drying period during the winter months. Rain will often lower the surface temperature as much as 50 F, but after five to sixteen days without rain, maximum surface temperatures again are reached. Young conifer seedlings died at surface temperatures of 147 to 152 F.

Surface soil temperatures are influenced by isolation which in turn is related to aspect and exposure. Loblolly pine (Pinus taeda L.) seeded on surface mine spoils grew 88 percent taller on the south slopes than on northern exposures (Thor and Kring, 1964). Planted trees had a 41 percent height advantage on southern exposures compared to northern slopes. Steep north slopes were exposed to less light intensity, thus the photosynthetic rate was slower. Also, the early warming of soil on the southern exposures resulted in a longer growing season.

Thompson (1971) found that the surface temperature on deep mine coal refuse banks was affected primarily by the ambient air temperature and the direction of the wind and only secondarily by the slope and aspect of the spoil.

Other variables that affect survival and growth on surface mine spoils are stoniness, texture, and stability of slope (Czapowskyj, 1973; Lowry, 1960; Limstrom, 1964; Marx, 1975). Loblolly pine seedlings planted on spoils are also susceptible to frost heaving during the winter months (Zarger, 1973).

The benefits of applying fertilizers on forest soils has been well documented. However, applications on surface mine spoil requires knowledge of the chemical and physical characteristics of both the fertilizers and the soil. Baker (1972) reported that some soils have exchange and reserve acid properties capable of withstanding heavy applications of alkaline-producing substances, such as urea, without adverse effects. He found that soils with large proportions of the total acidity in an exchangeable form cannot withstand excessive use of urea-type fertilizers without altering the equilibrium of the soil and adversely influencing the solubility and availability of essential nutrients.

On acid sites, urea ($NH_3$), will increase pH due to the alkaline soil solutions produced by the hydrolysis of this fertilizer (Beaton, 1973). Elements such as K, Ca, Na, and Mg are displaced by this urea solution. Phosphorus should be applied in the form of ordinary or superphosphate to help immobilize aluminum and to reduce the mobility of this element in the plant.

Zarger (1964) reported that ammonium nitrate yields the greatest percentage of plantable seedlings, greatest heights, stem diameters, and dry weights of pine nursery stock. However, Bengtson (1973) found that the low nitrogen recoveries from ammonium nitrate by young pines in Mississippi suggest that leaching and denitrification could amount to as much nitrogen loss as the volatile loss of ammonia from hydrolyzing urea. He also warned that the ammonium forms of nitrogen can induce physiological drought by the osmotic effects of soluble salts, as well as contribute to the movement of soil cations in percolating water, leading to both depletion of bases in the upper horizon and increased soil acidity.

Sludge has a mean N-P-K composition of approximately 2.4-2.3-0.3 (Gagnon, 1973). The advantages of sludge include a slowly releasing nutrient base for long lasting effects, the capacity to retain water during dry periods, and a more readily available form of nitrogen.

Nitrogen uptake by young pines is affected by (1) herbaceous competition, and (2) time of application (Baker et al., 1974). When fertilized at age three, about 46 percent of the nitrogen was utilized by pines and 27 percent was absorbed by the herbaceous competition. When fertilized at age four, the herbaceous competition was greater, resulting in a 58 percent nitrogen recovery by the herbaceous plants and a 14 percent recovery by the pines.

Farmer et al. (1970) reported that loblolly pine responded to fertilizers in the second and third year after application but that a diminished effect occurred in the fourth and fifth years. He attributed this to the declining influence of nitrogen.

Loblolly pine seedlings grew best on kaolin-clay spoils when fertilized with a complete fertilizer followed by a second application in the third or fifth year (May, 1977). When planted with a ground cover, however, fertilized pines grew more slowly due to competition.

Nutrients can also be supplied from natural sources. Nitrogen fixation is greatest at soil temperatures of 15 to 25 C (Wollum and Davey, 1975). Nitrification is optimum between pH 6.5 to 7.5; when pH is below 3.7 the process fails to function (Wilson and Stewart, 1955). Ammonia tends to accumulate in acid spoils but is low in neutral or alkaline spoils.

Fossil nitrogen is released from certain Pennsylvanian shales in the form of fixed ammonium (Cornwell and Stone, 1968). Intense weathering destroys the silicate lattices of carbonaceous shales, releasing fixed ammonium and other nitrogenous organic compounds. Spoils low in oxidizable sulfur do not undergo much silicate destruction, hence there is little release of nitrogen, regardless of total content or form.

Most fertilizer applications on surface mine spoils include the use of lime. The benefits of liming acid spoils are (1) adjusting the base saturation on the exchange complex of soil colloids, (2) neutralizing the excess acidity, and (3) inhibiting toxic concentrations of elements (Czapowskyj, 1973).

Plass (1969) found that lime reduced the toxicity of Mn, Fe, Cu, and Zn. He noticed that five tons of lime per acre gave the best growth but:

> Growth after the 10 ton per acre treatment was always less than after the other treatments. Also, the concentration of all elements except calcium, potassium, aluminum, and nitrogen was significantly reduced by this treatment. Therefore, heavy liming appears to have interfered with the absorption of essential nutrients.

May et al. (1973) found that one ton of lime per acre raised the pH of a kaolin-clay spoil from 4.8 to 6.2 to a depth of 15 cm, and two tons per acre raised the pH above 7.0, precipitating aluminum.

Ectomycorrhizal fungi, particularly <u>Pisolithus tinctorius</u>, are common on the roots of trees in forest environments and especially on adverse sites such as severely eroded soils and surface mine spoils (Marx, 1975, 1977). These fungi have above-ground fruiting bodies (basidiocarps) from which spores are disseminated by wind and water (Medve, 1976). An extensive hyphal system permeates a large soil volume and penetrates the root tissues of the host plant (Hacskaylo, 1972).

Numerous studies have shown that mycorrhizal trees exhibit greater nutrient uptake, more rapid growth, greater resistance to soil pH and temperature extremes, increased drought resistance, and increased disease resistance over non-mycorrhizal trees (Mikola, 1973;

Marx, 1969, 1970, 1975; Marx and Bryan, 1971; Marx and Zak, 1965; Vozzo and Hacskaylo, 1971).

The extensive hyphal network of mycorrhizal trees effectively increases the absorption surface of roots by 20 to 30 times (McComb, 1943). This increased root surface results in greater nutrient absorption by the host plant (Gray, 1969; Hacskaylo, 1972; Vogt, 1969). Nitrogen, phosphorus, and potassium are absorbed more readily by mycorrhizal plants (Harley, 1959; Marx and Bryan, 1975; Slankis, 1973).

Although non-mycorrhizal roots are as effective as mycorrhizal roots in the uptake of phosphorus, non-mycorrhizal roots quickly deplete the small soil volume around the root (Hacskaylo, 1969). In contrast, mycorrhizal roots continue to promote mycelial extensions and absorb a continual supply from a much larger soil volume.

Although the fungal mycelium absorbs more total phosphorus, only 10 percent actually reaches the plant; i.e., the fungus absorption to host transfer is at the rate of nine to one (Mejstrik and Krause, 1973; Harley, 1959). The fungal sheath acts as a primary reservoir of accumulated nutrients from which phosphorus steadily passes to the host plant.

It is argued, however, that the mycorrhizal plants will absorb more phosphorus than non-mycorrhizal plants, especially when the surrounding soil medium is low in that element (Kormaik et al., 1977). Thus, if an element is deficient and limiting plant growth that element will likely appear in higher concentrations in mycorrhizal plants. Tissue analysis of mycorrhizal pines showed 86 percent more nitrogen, 234 percent more phosphorus, and 75 percent more potassium than non-mycorrhizal pines (Hacskaylo, 1967).

McComb (1943) observed that (1) mycorrhizal pine seedlings had weights double those of non-mycorrhizal seedlings and (2) total height of mycorrhizal seedlings was 35 percent greater than non-mycorrhizal seedlings. After three growing seasons, mycorrhizal slash pine (Pinus elliottii Engelm.) grew up to eight feet tall while non-mycorrhizal pines grew only one foot tall (Vozzo and Hacskaylo, 1971). The fertilized but non-mycorrhizal pines became stunted and chlorotic while the non-fertilized but mycorrhizal seedlings were larger and more vigorous.

One of the greatest benefits of mycorrhizae to plantings on surface mine spoil is increased survival. Survival of Pisolithus tinctorius infected trees was 49 percent on a Kentucky coal mine spoil while in non-mycorrhizal pines or those with Thelephora terrestris survival was only 1 percent (Marx, 1977). Shoulders (1972) found that slash pine survival increased by one-third when inoculated with mycorrhizae. He concluded:

> Mycorrhizae either were themselves responsible for the higher survival of inoculated seedlings or influenced survival by modifying chemical composition of the planting stock, especially nitrogen-phosphorus ratios in roots and needles.

Pisolithus tinctorius increased survival of loblolly pine seedlings by 34 percent and Virginia pine (Pinus virginiana Mill.) by 36 percent over similar seedlings infected with Thelephora terrestris or sterile pines (Marx, 1975).

The greater survival rate of mycorrhizal trees on surface mines is likely due to the protection the fungus affords the tree from extremes of soil pH and temperature. Marx and Zak (1965) concluded that the mycorrhizal hyphae are able to buffer the high concentrations of iron and aluminum present in spoils having low pH. Marx (1977) found that mycorrhizal pine seedlings grew well in spoil with a pH as low as 3.4 to 3.8.

After five weeks during which root substrate temperatures were held at 40 C, 45 percent of non-mycorrhizal loblolly pine seedlings survived while 90 to 95 percent of the mycorrhizal ones lived (Marx and Bryan, 1971). Heat resistance of roots is especially beneficial for surface mine plantings where high soil temperatures often destroy entire plantings (Marx, 1975).

Schramm (1955) concluded that all pine trees planted in coal mine black wastes and subjected to high temperatures quickly succumbed or became stunted. He correlated seedling survival directly to the presence of mycorrhizae.

Mycorrhizae also increase drought resistance (Marx, 1975). The inoculation of seedling stock in nurseries reduces the trauma of field environmental conditions due primarily to the resistance of fungal roots to drought (Mikola, 1973).

Mycorrhizae protect the roots from many diseases and pathogens. The fungal mantle of ectotrophic mycorrhizae provides a mechanical and chemical barrier, preventing penetration of root tissues by highly infective vegetative mycelium and germ tubes of zoospores of certain pathogens (Marx, 1970). Slash pine, for instance, can be protected from Phytophthora cinnamoni (a pathogen which infects succulent feeder roots) by inoculation of several mycorrhizal forms (Ross and Marx, 1972; Marx, 1969; Marx and Davey, 1969). Non-inoculated seedlings had lower stem, foliar, and dry weights, fewer lateral roots, and became chlorotic.

Prolonged water impoundments, severe fires, and toxic chemicals used to control weeds, insects, and parasitic fungi may kill or retard the growth of mycorrhizae (Wilde, 1954). High soil fertility also tends to eliminate the fungus (Hacskaylo, 1969). High soil concentrations of nitrogen and phosphorus decreased the number of mycorrhizal roots in loblolly pine (Marx et al., 1977). Richards (1961) found that neutral or alkaline soils retard mycorrhizal development because of the higher amounts of N found in these soils.

# CHAPTER III

## OBJECTIVES

The objectives of this study were:

(1) To evaluate reclamation regulations concerning fertilizers and lime now in effect in Tennessee as they affect tree growth.

(2) To establish lime and fertilizer rates beneficial to the survival and growth of loblolly pine on surface mines in East Tennessee.

(3) To evaluate a wetting agent and mycorrhizal inoculations as methods for increasing survival and growth of loblolly pine on surface mines in East Tennessee.

# CHAPTER IV

# METHODS AND MATERIALS

Three study locations were selected on recently graded surface mines in East Tennessee. The intent was to conduct the study on several different surface mines at different elevations and in different stages of reclamation. The first was in the Cumberland Mountains about 12 miles west of Caryville, Tennessee. The second location was on the Cumberland Plateau, approximately eight miles west of Cagle, Tennessee, and the third was in the Cumberland Mountains approximately 12 miles northwest of Oliver Springs, Tennessee.

## A. Caryville Study Location

### 1. Description of Area

The Caryville location was at an elevation of approximately 2,800 feet. Because this elevation is above the recommended elevation for loblolly pine, eastern white pine (Pinus strobus L.) was planted on May 1, 1976. Due to poor survival and disturbances by contractors this experiment was later dropped from the study.

## B. Cagle Study Location

### 1. Description of Area

The Cagle location represented a surface mine already graded and planted to loblolly pine. Aside from these activities, State reclamation requirements had not been met. Two different study sites were established: (1) a young mine spoil on which 1-0 seedlings were planted in 1975, and (2) on older spoil planted in 1974. The land was owned by Hiwassee Land Company and planting was done by their personnel. The older planting had a northern aspect with a slope of approximately 15 percent, while the younger planting was undulating but generally faced southwest with an average slope of approximately 20 percent. The elevation of both plantings was approximately 1,850 feet. The coal seam mined was the Sewanee, the spoil from which is generally acid.

The soils at both sites were non-skeletal loams with rocks comprised mostly of shales. The average pH of the spoil in the older planting was 3.84 while in the younger planting it averaged 3.64. Phosphorus levels in the older spoil were 3.5 pounds per acre and 19 pounds per acre in the younger spoil to a depth of six inches. Potassium ranged from 142 pounds per acre in the older spoil to 111 pounds per acre in the younger spoil (Appendix B, Tables B-2 and B-3). For agricultural crops the soil levels of phosphorus were very low to medium while the potassium levels were medium.

In the older planting tree survival was uniformly good with an average height of 5.1 feet at the time of study establishment. The trees were heavily mycorrhizal, evidenced by numerous above-ground fruiting bodies (basidiocarps). Random samples of pine roots indicated that the fungus was _Pisolithus tinctorius_.

Survival in the younger planting was sporatic. The average tree height at the time of study establishment was 1.6 feet. Trees showed no evidence of mycorrhizae until late in the second year of the study.

2. Treatments and Data Collection

In June, 1976, 56 plots (each 0.035 acres in size) were established at Cagle. Fertilizers, lime, and grasses were applied following State requirements on June 15 and 16, 1976. These were:

(1) Grass planted at the rate of 50 pounds per acre of scarified Sericia lespedeza (*Lespedeza cuneata* (Dumont) E. Don.) and 25 pounds per acre of tall fescue (*Festuca arundubaceae* Schreb.).

(2) Fertilizer at 1,000 pounds of 10-10-10 per acre.

(3) Lime at four tons per acre.

A randomized complete block arrangement was used with two replications in each planting, for a total of four replications for each treatment. Table 1 gives a description of the 14 treatments used, and Figure 1 is a schematic diagram of the experimental plot layout.

Nitrogen was applied as ammonium nitrate ($NH_4NO_3$), phosphorus as concentrated superphosphate ($Ca(H_2PO_4)_2$), and potassium as muriate of potash ($K_2O$). The ground agriculture limestone had an average purity of 94 percent and a neutralizing power of 96.6 percent (Buckman and Brady, 1969).

Total tree heights were measured prior to treatment in June, 1976, September, 1976, June, 1977, and September, 1977. This gave three growth periods for evaluating response to treatments.

TABLE 1. Description of the treatments tested at the Cagle study location.

| No. | Treatment | Description | Notes |
|---|---|---|---|
| 14 | NPKL4 | 100 lbs/A. N, $P_2O_5$, $K_2O$ and 4 tons lime/A. | State requirement for fertilizer and lime |
| 10 | NPKL2 | 100 lbs/A. N, $P_2O_5$, $K_2O$ and 2 tons lime/A. | State requirement for fert. and lime at 1/2 State requirement |
| 5 | NPK | 100 lbs/A. N, $P_2O_5$, and $K_2O$ | State requirement for fertilizer but w/o lime |
| 6 | (1/2N)PK | 50 lbs/A. N, and 100 lbs/A. $P_2O_5$, $K_2O$ | One-half State requirement N, full req. P and K but w/o lime |
| 11 | L4 | 4 tons lime/A. | State req. for lime w/o fertilizer |
| 7 | L2 | 2 tons lime/A | One-half State requirement for lime w/o fertilizer |
| 12 | NL4 | 100 lbs/A. N and 4 tons lime/A. | State req. for N and lime w/o P, K |
| 13 | NPL4 | 100 lbs/A. N, $P_2O_5$, and 4 tons lime/A. | State req. for N, P, and lime w/o K |
| 8 | NL2 | 100 lbs/A. N, and 2 tons lime/A. | State req. for N w/o P, K and 1/2 req. lime |
| 9 | NPL2 | 100 lbs/A. N, $P_2O_5$, and 2 tons lime/A | State req. for N, P w/o K, and 1/2 req. lime |
| 2 | N | 100 lbs/A. N | State req. for N, w/o P, K, or lime |
| 3 | P | 100 lbs/A. $P_2O_5$ | State req. for P w/o N, K, of lime |
| 4 | NP | 100 lbs/A. | State req. for N, P w/o K or lime |
| 1 | Control | | Check treatment for fertilizer and lime |

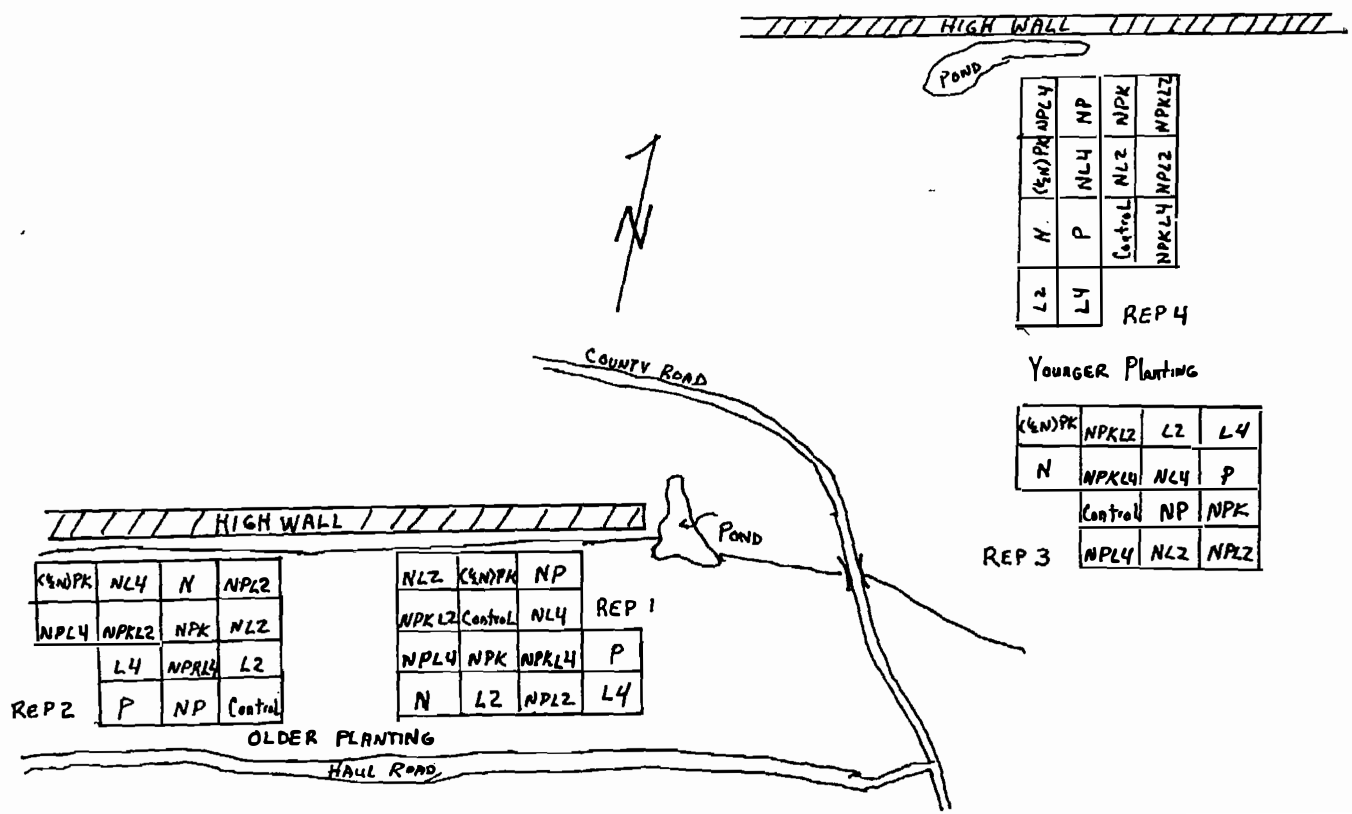


FIGURE 1. Experimental plot layout of the Cagle study location.

Soil samples were sent to the Agriculture Extension Service, Nashville, Tennessee, and analyzed for pH, phosphorus, and potassium. In June, 1976, prior to treatment, four random soil samples were taken from each plot and composited. In June, 1977, four random samples from each plot were obtained and analyzed separately to evaluate within plot variation. These sampling procedures were used to classify pH fluctuations within and between study plots.

## C. Oliver Springs Study Location

### 1. Description of Area

The Oliver Springs study location was on Wind Rock Mountain on a graded backfill of the Dean coal seam. The planting site was on a northwest aspect at an elevation of approximately 2,250 feet.

Spoil was a skeletal loam with underlying shale. Soil pH ranged from 4.4 to 6.2. Phosphorus levels averaged 39 pounds per acre and potassium 140 pounds per acre, which for agricultural crops was high for phosphorus and medium for potassium.

Prior to study establishment, the area had been graded according to current State requirements but no trees had been planted. Loblolly pine from Hiwassee Land Company's nursery in Alabama was planted in the spring of 1977. Seedling stock was from North Georgia, a source that has been exceptionally hardy when planted north of its native range.

### 2. Treatments and Data Collection

Sixteen trees were planted in each of the 32 treatment plots (each 0.013 acres in size) at a spacing of six feet by six feet. A randomized complete block arrangement was used with four replications of eight treatments. Table 2 gives a description of the treatments and a schematic diagram of the experimental plot layout is given in Figure 2.

The variables tested were: (1) fertilizer, (2) mycorrhizal inoculation, and (3) a wetting agent advertised as effective in increasing soil permeability and water availability by breaking the surface tension. Nitrogen was applied as ammonium nitrate and phosphorus as concentrated superphosphate. Fertilizer was applied to individual trees. The rooting area of a seedling was estimated to be one and one-half square feet, and a per-acre rate of 100 pounds of N and $P_2O_5$ was reduced to fertilize only this area at that rate. Mycorrhizal inoculations involved a combination of three methods:

(1) Dipping the seedling roots in a slurry mixture containing the chopped basidiocarps of Pisolithus tinctorius;

(2) Dusting the roots just dipped with the spores of dry basidiocarps; and

(3) Dropping several pieces of mycorrhizal rootlets into the planting hole.

All mycorrhizal inoculum was obtained from the Cagle study location. The wetting agent was sprayed on the soil surface using a hand-operated pump sprayer. The application rate was six ml of agent to two gallons of water per plot.

To determine the growth responses to treatments, total height and survival were measured in October, 1977. Soil samples were analyzed by the Agriculture Extension Service, Nashville, Tennessee.

TABLE 2. Description of the treatments tested at the Oliver Springs study location.

| No. | Treatment | Description |
|---|---|---|
| 1 | Control | Check treatment for fertilizer and other treatments |
| 2 | W. A. | Wetting agent |
| 3 | Mycor. | Mycorrhizal inoculum was applied to trees |
| 4 | Fert. | N at 23 grams and $P_2O_5$ at 20 grams per gree were applied |
| 5 | W. A. and Fert. | The above rates of N and $P_2O_5$ plus wetting agent were applied |
| 6 | W. A. and Mycor. | Trees were inoculated with mycorrhizae plus wetting agent |
| 7 | Mycor. and Fert. | The above rates of fertilizer were applied to mycorrhizae-inoculated trees |
| 8 | W. A., Mycor., and Fert. | Trees received wetting agent, fertilizer, and mycorrhizal inoculum |

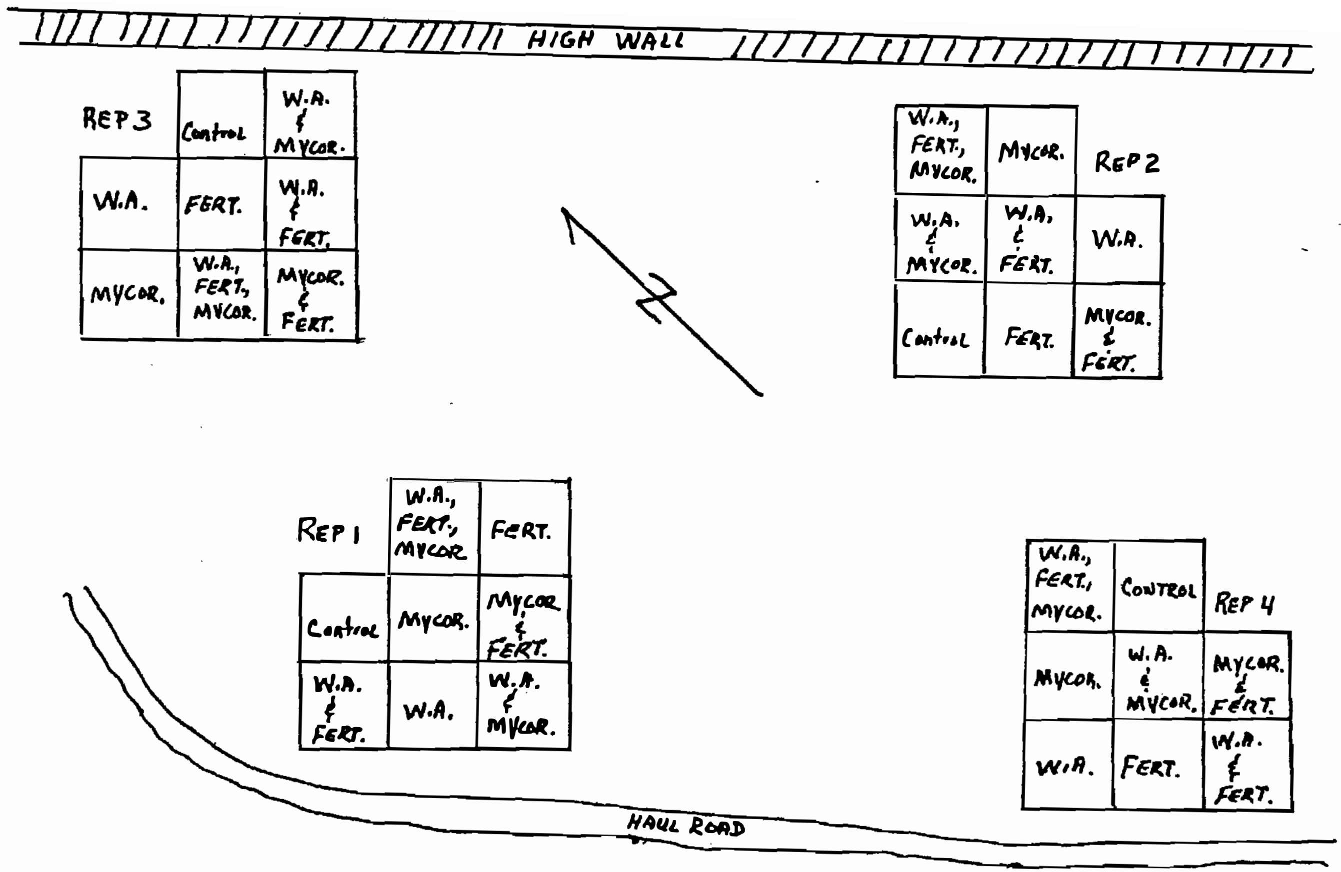


FIGURE 2. Experimental plot layout of the Oliver Springs study location.

CHAPTER V

RESULTS AND DISCUSSION

A. Cagle Study

1. Older Planting

Of the three growth periods studied (summer, 1976; spring, 1977; and summer, 1977), height growth was greatest during the summer of 1977, possibly reflecting more favorable weather. However, growth over control was more apparent the previous summer (1976), following treatment applications early that June. Poor growth in the spring of 1977 was probably related to winter injury (dessicated foliage and dieback).

The winter of 1976-1977 was unusually cold. Two days in December had a maximum daily temperature below freezing, while in January, 16 days had a maximum daily temperature less than freezing and 7 days had a minimum daily temperature below 0 F (Table B-1, Appendix B). More than 30 percent of the pines in some plots showed winter injury following the first winter (Table 3). Winter injury appeared to be more severe on trees that grew the most the previous summer (1976).

Although winter damage was still apparent, trees were recovering by the end of the second summer. One or more lateral branches had replaced the killed terminals resulting in curvature of the main stem and/or multiple terminals.

Growth of trees receiving nitrogen was greater than controls the season of application (first summer) with the exception of the treatment

TABLE 3. Winter damage between the first and second growing seasons in the older planting at the Cagle study location.

| Treatment | Percent of Growth Over Control First Season | Percent of Trees Showing Winter Damage |
|---|---|---|
| Control | -- | 15 |
| N | 5 | 21 |
| P | -10 | 4 |
| NP | 30 | 22 |
| NPK | 5 | 15 |
| (1/2N)PK | 25 | 24 |
| Lime @ 2T/A. | 5 | 22 |
| NL2 | 10 | 28 |
| NPL2 | 15 | 30 |
| NPKL2 | 15 | 28 |
| Lime @ 4T/A. | -10 | 22 |
| NL4 | 15 | 41 |
| NPL4 | 10 | 9 |
| NPKL4 | -5 | 35 |

duplicating State requirements (NPKL4) (Figure 3). Nitrogen appeared effective at both the 50 and 100 pound per acre levels during the spring of 1977 and for the total study period.

Despite the low soil levels of phosphorus, P had no effect when applied without nitrogen. However, it appeared to prolong the response of N (Figure 3). Potassium in combination with N and P had no effect on the growth. Soil levels of this nutrient appeared to be adequate.

Growth was greatest when both N and P were added. The only statistically significant (.05 level) response was for this treatment during the summer of 1976 (Table A-1, Appendix A) and only in this treatment was there a growth increase over control in all growth periods.

Lime at 2 tons per acre (one-half the State requirement) in combination with a complete fertilizer (NPK) appeared to improve growth in all periods except the spring of 1977, which was probably related to winter injury the previous winter. At 2 tons per acre, lime appeared to increase the response of N and P. Lime alone at 2 tons per acre appeared to improve growth each period except the spring of 1977 where winter injury was probably a factor. With the exception of the season of application (summer, 1976), growth was less than control in all plots receiving lime at 4 tons per acre (State requirements) with or without fertilizers.

2. Younger Planting

As in the older planting height growth in all treatments was greatest during the summer of 1977. Growth over control, however, was more apparent the season of application (summer, 1976). Average

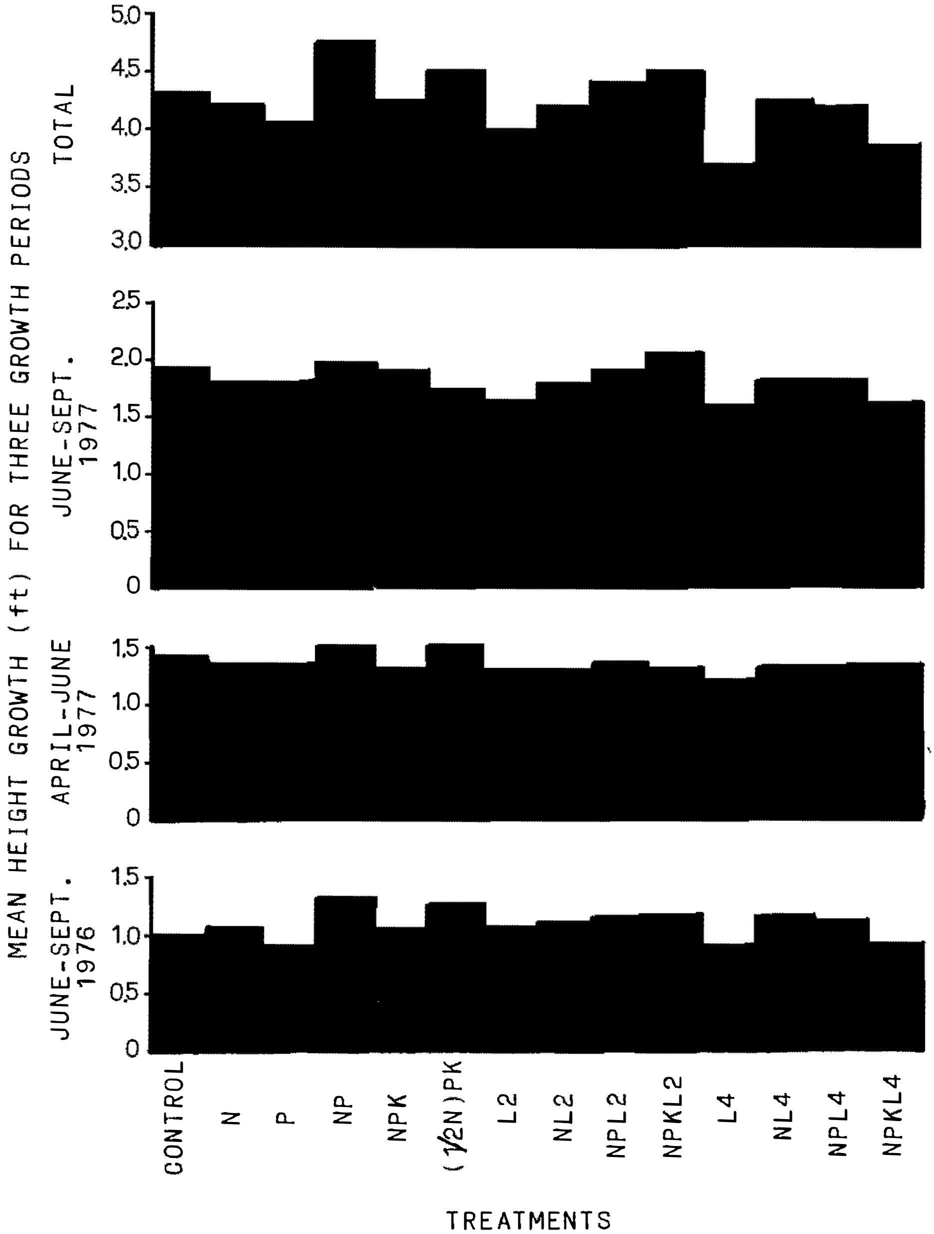


FIGURE 3. Mean height growths in the older planting at the Cagle study location.

height growth and differences among treatments were small the spring of 1977 (Figure 4). Once again, poor growth during this period was probably related to winter injury. Over 50 percent of the trees in some plots were damaged; however, damage appeared to be related more to tree position and exposure than to treatment effects.

With the exception of the NP treatment, N appeared to stimulate growth the season of application (summer, 1976) (Figure 4). However, in the spring and summer of 1977, nitrogen alone had no effect, indicating a short response duration.

Phosphorus appeared to decrease growth, especially when added alone and to a lesser extent when added with N (Figure 4). Potassium appeared to offset the growth-depressing effect of P. Although K levels were slightly lower than in the older spoil, this difference did not provide an adequate explanation for the greater apparent influence of K in the younger planting.

Growth was greater in plots limed at 2 tons per acre except in the spring of 1977, when winter injury may have been a factor; lime at 4 tons per acre had no effect. Lime at 2 tons per acre and nitrogen appeared to give the greatest growth increase over all growth periods (Figure 4). Although lime at the 2 ton rate appeared superior over this short study period, when combined with fertilizers the 4 ton rate appeared to increase growth. This was especially true with a complete fertilizer (State requirement).

### 3. Discussion

In the older spoil, growth was greatest over the study period in the NP treatment without lime, while in the younger planting N with

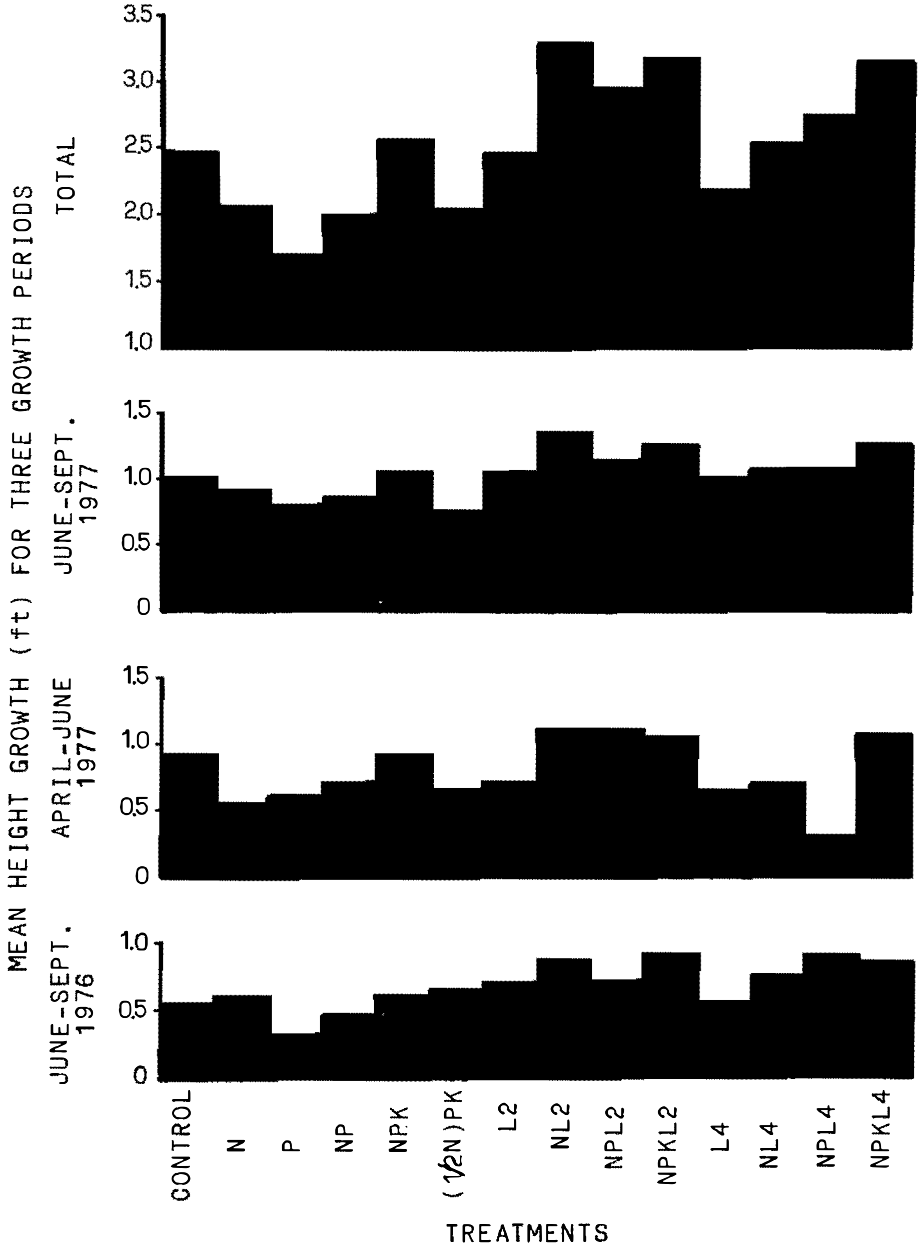


FIGURE 4. Mean height growths in the younger planting at the Cagle study location.

2 tons of lime appeared to provide the greatest growth. Lime thus appeared to be more important in the younger planting.

Several factors may contribute to the difference in apparent treatment response between the two plantings. The spoil in the younger planting was much more heterogeneous. Within plot pH variation was greater than 1.0 in 46 percent of the plots on the younger spoil but in only 25 percent on the older spoil. The older spoil may have stabilized to a greater extent, having a longer time for toxic metals to leach out of the surface layers. This may explain why fertilizers without lime appeared more effective in the older spoil.

The absence of mycorrhizae in the younger spoil may account for the greater apparent response there to soil amendments. Fertilizers added to mycorrhizal trees on the older spoil may have decreased the vigor of the mycorrhizae, offsetting any response to treatments. This phenomenon has been shown in past studies (Hacskaylo, 1969; Marx et al., 1977). Under such conditions fertilization would have been more important in providing nutrients in the younger spoil where mycorrhizae were either absent or only weakly developed.

Abundant mycorrhizae may also explain the absence of a strong growth response to liming in the older spoil. Past studies have shown that mycorrhizae is able to buffer toxic quantities of metals in acid spoils (Marx and Zak, 1965; Marx, 1977).

The short duration of growth responses in several of the treatments may be explained by dry soils. Richeson (1976) found short duration responses to fertilizers on excessively dry sites. He concluded that fertilization of dry sites is not economically feasible.

Over the total study period, lime alone did not increase tree growth on either site. However, combined with an increasing nutrient complement in the order N, NP, and NPK, lime at 2 tons per acre on the older spoil and at both 2 and 4 tons per acre on the younger spoil appeared to increase growth (Figures 3 and 4, pages 28 and 30, respectively). While liming appears to be more important on younger spoil and where complete fertilizers were used, the short duration of the study did not permit an adequate evaluation of its effect.

Grass planted in both spoils failed. This was probably due to the time of application (June) and the acidity of the spoil.

## B. Oliver Springs Study

Although treatment response was not statistically significant, trees inoculated with mycorrhizae survived better than controls (97 percent compared to 61 percent) and grew 21 percent higher (Appendix A, Tables A-3 and A-4). Random samples of pine roots showed that those trees inoculated with mycorrhizae had developed the characteristic symptoms of *Pisolithus tinctorius*. The time limitations of the study prevented the evidence of fruiting bodies or other signs of well-established mycorrhizal inoculation. Mycorrhizae will give greater growth responses once its development has matured (Marx, 1975).

The wetting agent and NP fertilizer appeared to increase growth but they decreased survival. Growth differences were significant compared to the large differences in survival.

Treatment response and survival were strongly related to grass competition. Trees planted in heavy grass were difficult to locate after one growing season. Where lovegrass (Eragrostis curvula (Schard) Ness) was predominant, tree survival was exceedingly poor (Table 4). In contrast, those blocks having a light to medium cover of fescue showed the highest tree survival. May (1977) and Baker et al. (1974) found that fertilizers tended to increase grass competition and decrease the survival of trees.

TABLE 4. Tree survival and grass competition at the Oliver Springs study location.

| Block | Percent Tree Survival | Predominant Grass Species | Level of Grass Cover[a] |
|---|---|---|---|
| 1 | 11.5 | Lovegrass | Heavy |
| 2 | 26.0 | Fescue | Heavy |
| 3 | 72.5 | Fescue | Light |
| 4 | 53.0 | Fescue | Medium |

[a]Light cover--less than 50 percent of surface area in grass; Medium cover--between 50 and 75 percent of surface area in grass; and Heavy cover--greater than 75 percent of surface area in grass.

## CHAPTER IV

## SUMMARY AND CONCLUSIONS

Findings relevant to efforts to improve surface mine reclamation in Tennessee were:

1. The State requirements for fertilizer and lime (NPK and lime at 4 tons/A. appeared to increase growth in non-mycorrhizal loblolly pine plantings on recently disturbed spoil. In older spoil (mycorrhizal) fertilizers at the required level but with lime at 2 tons per acre (one-half State requirements) appeared to increase growth.

2. Nitrogen was the single most important element. It increased growth when applied at both 50 and 100 pound per acre levels with P in the older spoil and at the 100 pound level when applied with K and lime in the younger spoil.

3. Phosphorus was effective only when combined with nitrogen.

4. The only statistically significant growth increase was in the NP treatment the first season.

5. Winter damage was greater on those trees that grew the most the previous summer.

6. Pines growing on older spoil (mycorrhizal) appeared to require less lime than did those growing on young spoil (non-mycorrhizal). On young spoil amendments appeared to be necessary for effective use of fertilizer applications.

7. Duration of response to fertilizers in young spoil (non-mycorrhizal) was longer when lime was added at both 2 and 4 tons/A. Lime at 2 tons per acre (one-half State requirements) was more effective than at 4 tons per acre in the older spoil.

8. Pines planted on a surface mine reclaimed according to State requirements for grass and fertilizers exhibited poor survival because of grass competition.

9. On a young coal spoil, fertilized trees grew slightly more but exhibited the poorest survival.

10. Although growth was slightly greater in plots treated with a wetting agent, survival was extremely poor.

11. Mycorrhizal inoculation was successful on a young coal spoil where inoculated pines survived much better and grew slightly more than pines not inoculated.

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## LITERATURE CITED

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APPENDICES

## APPENDIX A

TABLE A-1. Ranking of treatments according to decreasing mean height growth and Duncan's Test at the older planting at the Cagle study location.

| Treatment No. | Treatment Description | Rank | Growth Mean (Ft) | Change Over Control (%) | Duncan's Test |
|---|---|---|---|---|---|
| June-Sept., 1976 | | | | | |
| 4 | NP | 1 | 1.30 | 30 | |
| 6 | (1/2N)PK | 2 | 1.25 | 25 | |
| 9 | NPL2 | 3 | 1.15 | 15 | |
| 10 | NPKL2 | 4 | 1.15 | 15 | |
| 12 | NL4 | 5 | 1.15 | 15 | |
| 8 | NL2 | 6 | 1.10 | 10 | |
| 13 | NPL4 | 7 | 1.10 | 10 | |
| 2 | N | 8 | 1.05 | 5 | |
| 5 | NPK | 9 | 1.05 | 5 | |
| 7 | L2 | 10 | 1.05 | 5 | |
| 1 | Control | 11 | 1.00 | -- | |
| 14 | NPKL4 | 12 | 0.95 | - 5 | |
| 3 | P | 13 | 0.90 | -10 | |
| 11 | L4 | 14 | 0.90 | -10 | |
| April-June, 1977 | | | | | |
| 4 | NP | 1 | 1.50 | 7.1 | |
| 6 | (1/2N)PK | 2 | 1.50 | 7.1 | |
| 1 | Control | 3 | 1.40 | --- | |
| 2 | N | 4 | 1.35 | - 3.6 | |
| 3 | P | 5 | 1.35 | - 3.6 | |
| 9 | NPL2 | 6 | 1.35 | - 3.6 | |
| 5 | NPK | 7 | 1.30 | - 7.1 | |
| 7 | L2 | 8 | 1.30 | - 7.1 | |
| 8 | NL2 | 9 | 1.30 | - 7.1 | |
| 10 | NPKL2 | 10 | 1.30 | - 7.1 | |
| 12 | NL4 | 11 | 1.30 | - 7.1 | |
| 13 | NPL4 | 12 | 1.30 | - 7.1 | |
| 14 | NPKL4 | 13 | 1.30 | - 7.1 | |
| 11 | L4 | 14 | 1.20 | -14.3 | |

TABLE A-1. Continued.

| Treatment No. | Treatment Description | Rank | Growth Mean (Ft) | Change Over Control (%) | Duncan's Test |
|---|---|---|---|---|---|
| **June-Sept., 1977** | | | | | |
| 10 | NPKL2 | 1 | 2.05 | 7.9 | |
| 4 | NP | 2 | 1.95 | 2.6 | |
| 5 | NPK | 3 | 1.90 | 0 | |
| 9 | NPL2 | 4 | 1.90 | 0 | |
| 1 | Control | 5 | 1.90 | -- | |
| 2 | N | 6 | 1.80 | -5.3 | |
| 3 | P | 7 | 1.80 | -5.3 | |
| 8 | NL2 | 8 | 1.80 | -5.3 | |
| 12 | NL4 | 9 | 1.80 | -5.3 | |
| 13 | NPL4 | 10 | 1.80 | -5.3 | |
| 6 | (1/2N)PK | 11 | 1.75 | -7.9 | |
| 7 | L2 | 12 | 1.65 | -13.2 | |
| 11 | L4 | 13 | 1.60 | -15.8 | |
| 14 | NPKL4 | 14 | 1.60 | -15.8 | |
| **Total** | | | | | |
| 4 | NP | 1 | 4.75 | 10.5 | |
| 6 | (1/2N)PK | 2 | 4.50 | 4.7 | |
| 10 | NPKL2 | 3 | 4.50 | 4.7 | |
| 9 | NPL2 | 4 | 4.40 | 2.3 | |
| 1 | Control | 5 | 4.30 | --- | |
| 12 | NL4 | 6 | 4.25 | -1.2 | |
| 5 | NPK | 7 | 4.25 | -1.2 | |
| 2 | N | 8 | 4.20 | -2.3 | |
| 8 | NL2 | 9 | 4.20 | -2.3 | |
| 13 | NPL4 | 10 | 4.20 | -2.3 | |
| 3 | P | 11 | 4.05 | -5.8 | |
| 7 | L2 | 12 | 4.00 | -6.9 | |
| 14 | NPKL4 | 13 | 3.85 | -10.5 | |
| 11 | L4 | 14 | 3.70 | -14.0 | |

TABLE A-2. Ranking of treatments according to decreasing mean height growth and Duncan's Test at the younger planting at the Cagle study location.

| Treatment No. | Treatment Description | Rank | Growth Mean (Ft) | Change Over Control (%) | Duncan's Test |
|---|---|---|---|---|---|
| June-Sept., 1976 | | | | | |
| 10 | NPKL2 | 1 | 0.90 | 64 | |
| 13 | NPL4 | 2 | 0.90 | 64 | |
| 8 | NL2 | 3 | 0.85 | 55 | |
| 14 | NPKL4 | 4 | 0.85 | 55 | |
| 12 | NL4 | 5 | 0.75 | 36 | |
| 7 | L2 | 6 | 0.70 | 27 | |
| 9 | NPL2 | 7 | 0.70 | 27 | |
| 6 | (1/2N)PK | 8 | 0.65 | 18 | |
| 2 | N | 9 | 0.60 | 9 | |
| 5 | NPK | 10 | 0.60 | 9 | |
| 11 | L4 | 11 | 0.55 | 0 | |
| 1 | Control | 12 | 0.55 | -- | |
| 4 | NP | 13 | 0.45 | -18 | |
| 3 | P | 14 | 0.30 | -45 | |
| April-June, 1977 | | | | | |
| 8 | NL2 | 1 | 1.10 | 22 | |
| 9 | NPL2 | 2 | 1.10 | 22 | |
| 10 | NPKL2 | 3 | 1.05 | 17 | |
| 14 | NPKL4 | 4 | 1.05 | 17 | |
| 5 | NPK | 5 | 0.90 | 0 | |
| 1 | Control | 6 | 0.90 | -- | |
| 12 | NL4 | 7 | 0.75 | -17 | |
| 4 | NP | 8 | 0.70 | -22 | |
| 7 | L2 | 9 | 0.70 | -22 | |
| 11 | L4 | 10 | 0.65 | -28 | |
| 6 | (1/2N)PK | 11 | 0.65 | -28 | |
| 3 | P | 12 | 0.60 | -33 | |
| 2 | N | 13 | 0.55 | -39 | |
| 13 | NPL4 | 14 | 0.30 | -67 | |

TABLE A-2. Continued.

| Treatment No. | Treatment Description | Rank | Growth Mean (Ft) | Change Over Control (%) | Duncan's Test |
|---|---|---|---|---|---|
| June-Sept., 1977 | | | | | |
| 8 | NL2 | 1 | 1.35 | 35 | |
| 10 | NPKL2 | 2 | 1.25 | 25 | |
| 14 | NPKL4 | 3 | 1.25 | 25 | |
| 9 | NPL2 | 4 | 1.15 | 15 | |
| 5 | NPK | 5 | 1.05 | 5 | |
| 7 | L2 | 6 | 1.05 | 5 | |
| 12 | NL4 | 7 | 1.05 | 5 | |
| 13 | NPL4 | 8 | 1.05 | 5 | |
| 11 | L4 | 9 | 1.00 | 0 | |
| 1 | Control | 10 | 1.00 | -- | |
| 2 | N | 11 | 0.90 | -10 | |
| 4 | NP | 12 | 0.85 | -15 | |
| 3 | P | 13 | 0.80 | -20 | |
| 6 | (1/2N)PK | 14 | 0.75 | -25 | |
| Total | | | | | |
| 8 | NL2 | 1 | 3.30 | 35 | |
| 10 | NPKL2 | 2 | 3.20 | 31 | |
| 14 | NPKL4 | 3 | 3.15 | 29 | |
| 9 | NPL2 | 4 | 2.95 | 20 | |
| 13 | NPL4 | 5 | 2.75 | 12 | |
| 5 | NPK | 6 | 2.55 | 4 | |
| 12 | NL4 | 7 | 2.55 | 4 | |
| 7 | L2 | 8 | 2.45 | 0 | |
| 1 | Control | 9 | 2.45 | -- | |
| 11 | L4 | 10 | 2.20 | -10 | |
| 6 | (1/2N)PK | 11 | 2.05 | -16 | |
| 2 | N | 12 | 2.05 | -16 | |
| 4 | NP | 13 | 2.00 | -18 | |
| 3 | P | 14 | 1.70 | -31 | |

TABLE A-3. Ranking of treatments according to decreasing mean height growth and Duncan's Test at the Oliver Springs study location.

| Treatment No. | Treatment Description | Rank | Growth Mean (Ft) | Change Over Control (%) | Duncan's Test |
|---|---|---|---|---|---|
| 3 | Mycor. | 1 | 0.875 | 21 | |
| 2 | Wetting Agent | 2 | 0.875 | 21 | |
| 5 | W.A. & Fert. | 3 | 0.850 | 17 | |
| 6 | W.A. & Mycor. | 4 | 0.850 | 17 | |
| 7 | Mycor. & Fert. | 5 | 0.800 | 10 | |
| 4 | Fert. | 6 | 0.750 | 3 | |
| 1 | Control | 7 | 0.725 | -- | |
| 8 | W.A., Mycorr., & Fert. | 8 | 0.575 | -21 | |

TABLE A-4. Ranking of treatments according to decreasing survival and Duncan's Test at the Oliver Springs study location.

| No. | Description | Rank | Survival (%) | Change Over Control (%) | Duncan's Test |
|---|---|---|---|---|---|
| 3 | Mycor. | 1 | 97 | 59 | |
| 1 | Control | 2 | 61 | -- | |
| 6 | W.A. & Mycor. | 3 | 49 | -20 | |
| 7 | Mycor. & Fert. | 4 | 48 | -21 | |
| 2 | Wetting Agent | 5 | 39 | -36 | |
| 8 | W.A., Mycor., & Fert. | 6 | 39 | -36 | |
| 5 | W.A. & Fert. | 7 | 26 | -57 | |
| 4 | Fert. | 8 | 25 | -59 | |

## APPENDIX B

TABLE B-1. Mean monthly temperatures and precipitation for the Cagle and Oliver Springs study locations.

| Year | Statistics | Jan. | Feb. | Mar. | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Monteagle Station (Approx. 20 miles S.W. of Cagle study location) | | | | | | | | | | | | | |
| 1976 | Temp. | 32.3 | 47.8 | 52.1 | 57.6 | 60.0 | 69.2 | 72.6 | 71.1 | 65.5 | 52.0 | 40.0 | 36.6 |
| | Precip. | 4.66 | 3.12 | 5.34 | 1.31 | 8.45 | 6.86 | 3.83 | 1.85 | 6.02 | 6.55 | 2.24 | 4.60 |
| 1977 | Temp. | 22.3 | 38.7 | 51.7 | --- | 66.4 | 71.8 | 76.6 | 74.2 | 68.9 | 54.6 | 49.9 | 37.3 |
| | Precip. | 5.78 | 3.62 | 9.60 | 10.17 | 5.43 | 4.10 | 1.99 | 5.50 | 9.63 | 6.96 | 12.29 | 3.69 |
| Crossville Station (Approx. 40 miles W. of Oliver Springs study location) | | | | | | | | | | | | | |
| 1977 | Temp. | 22.1 | 37.7 | 51.8 | 59.9 | 67.8 | 72.8 | 78.1 | 76.9 | 71.5 | 53.4 | 50.0 | 36.8 |
| | Precip. | 2.42 | 2.58 | 5.75 | 11.07 | 3.55 | 4.83 | 2.59 | 5.55 | 7.19 | 6.24 | 8.30 | 4.03 |

TABLE B-2. Soil analysis (pH, P, and K) for 1976 and 1977 in the older planting at the Cagle study location.

| Treatment | | pH | | P(lbs/A.) | | K(lbs/A.) | |
|---|---|---|---|---|---|---|---|
| No. | Description | 1976 | 1977 | 1976 | 1977 | 1976 | 1977 |
| 1 | Control | 3.7 | 4.1 | 4 | 3 | 120 | 152 |
| 2 | N | 3.9 | 4.0 | 3 | 3 | 120 | 157 |
| 3 | P | 4.0 | 4.2 | 3 | 7 | 170 | 172 |
| 4 | NP | 3.7 | 4.0 | 4 | 6 | 130 | 145 |
| 5 | NPK | 3.6 | 4.1 | 7 | 6 | 125 | 172 |
| 6 | (1/2N)PK | 3.8 | 4.3 | 3 | 5 | 150 | 167 |
| 7 | L2 | 3.9 | 4.5 | 4 | 3 | 145 | 169 |
| 8 | NL2 | 4.0 | 4.3 | 3 | 3 | 140 | 136 |
| 9 | NPL2 | 3.9 | 4.5 | 4 | 7 | 185 | 161 |
| 10 | NPKL2 | 4.0 | 5.0 | 5 | 17 | 160 | 165 |
| 11 | L4 | 3.8 | 4.8 | 5 | 6 | 160 | 162 |
| 12 | NL4 | 3.9 | 5.0 | 3 | 3 | 155 | 206 |
| 13 | NPL4 | 3.7 | 4.5 | 4 | 10 | 110 | 147 |
| 14 | NPKL4 | 3.7 | 4.2 | 3 | 8 | 120 | 149 |

TABLE B-3. Soil analysis (pH, P, and K) for 1976 and 1977 in the younger planting at the Cagle location.

| No | Treatment Description | pH 1976 | pH 1977 | P(lbs/A.) 1976 | P(lbs/A.) 1977 | K(lbs/A.) 1976 | K(lbs/A.) 1977 |
|---|---|---|---|---|---|---|---|
| 1 | Control | 3.5 | 3.9 | 17 | 11 | 125 | 119 |
| 2 | N | 3.3 | 3.8 | 11 | 10 | 60 | 70 |
| 3 | P | 3.4 | 3.8 | 18 | 35 | 115 | 89 |
| 4 | NP | 4.0 | 4.0 | 36 | 22 | 120 | 114 |
| 5 | NPK | 3.9 | 4.4 | 20 | 22 | 120 | 149 |
| 6 | (1/2N)PK | 3.6 | 4.0 | 15 | 23 | 110 | 116 |
| 7 | L2 | 3.3 | 4.0 | 12 | 12 | 55 | 95 |
| 8 | NL2 | 3.9 | 5.1 | 28 | 21 | 110 | 132 |
| 9 | NPL2 | 3.7 | 4.5 | 20 | 24 | 135 | 132 |
| 10 | NPKL2 | 4.1 | 4.7 | 22 | 40 | 155 | 183 |
| 11 | L4 | 3.7 | 4.2 | 20 | 10 | 115 | 97 |
| 12 | NL4 | 3.5 | 4.4 | 10 | 11 | 115 | 108 |
| 13 | NPL4 | 3.5 | 4.6 | 16 | 18 | 90 | 105 |
| 14 | NPKL4 | 3.6 | 4.5 | 19 | 18 | 130 | 161 |

# VITA

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